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TORQUE TRANSMISSION THROUGH ROCK BOLTS

by

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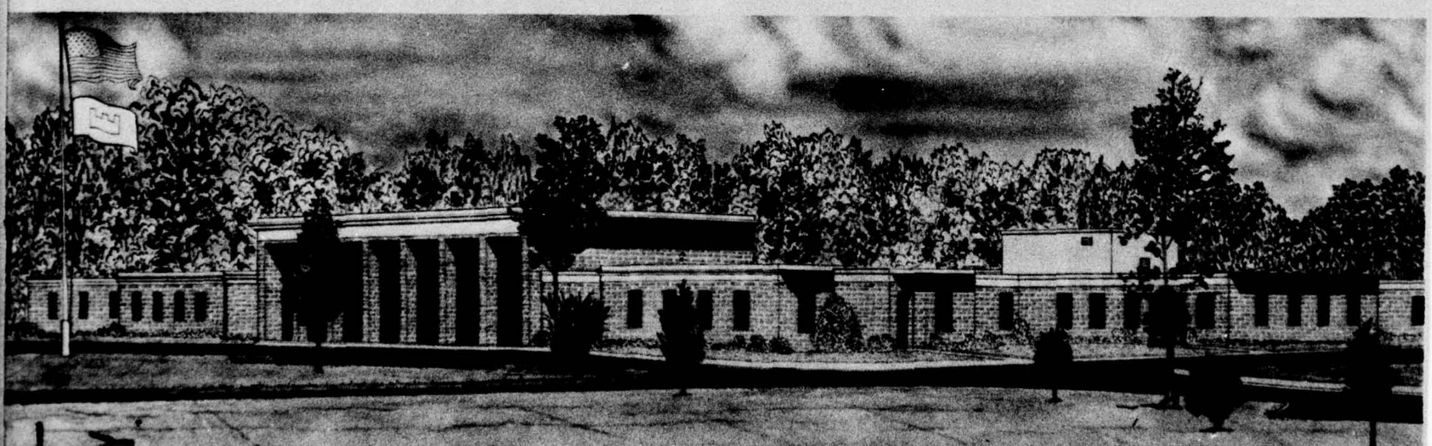
April 1977

Final Report



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A laboratory testing program was undertaken to determine the effectiveness of a 1000-ft-lb impact wrench in transmitting torque to the anchor shells of various lengths of rock bolts. The investigation was limited to testing of one impact wrench on 2-, 4-, 6-, 8-, 10-, 12-, 16-, and 24-ft-length rock bolts. Results of torque tests indicated that transmitted torque generally decreases with increasing bolt length according to the equation: → next page

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cont

$$T = \sqrt{\frac{c}{L}}$$ square root of (c/L)

where c is a constant dependent upon bolt size and configuration and upon the type of impact wrench used. It was recommended that impact wrenches to be used for torquing rock bolts be proof tested in the laboratory and in the field before acceptance.

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PREFACE

The investigations reported herein were conducted by the U. S. Army Engineer Waterways Experiment Station (WES). The work was sponsored jointly by the Office, Chief of Engineers, under the Facilities Investigation and Studies Program, Project No. 4K078012AQ61/02/208, "Criteria for Tunnel and Cavity Support Systems," and the U. S. Army Engineer District, Omaha, under the authority of Intra-Army Order for Reimbursable Services No. 6396, dated 10 June 1975.

The laboratory testing was accomplished during the period August-December 1975 by the Soils and Pavements Laboratory (S&PL). This report was prepared by Mr. G. H. Bragg, Jr., who was responsible for the testing. The investigation was accomplished under the direct supervision of Mr. Jerry S. Huie, Chief, Design Investigations Branch, Engineering Geology and Rock Mechanics Division (EGRMD), of the S&PL, and under the general supervision of Mr. Don C. Banks, Chief, EGRMD, and Mr. James P. Sale, Chief, S&PL.

Directors of WES during the conduct of this testing and the preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
pounds (mass)	0.4535924	kilograms
tons (2000 pounds, mass)	907.1847	kilograms
pounds (force)	4.448222	newtons
pounds (force) per square inch	6894.757	pascals
foot-pounds	1.355818	newton-metres
cubic feet per minute	0.02831685	cubic metres per minute

TORQUE TRANSMISSION THROUGH ROCK BOLTS

PART I: INTRODUCTION

Objective

1. The objective of this investigation was to determine the effectiveness of a 1000-ft-lb* impact wrench in transmitting torque to the anchor shells of various lengths of rock bolts. The research was conducted to provide laboratory data for comparison with results of field rock bolt torquing at the North American Air Defense Command and to provide information for future torquing specifications.

Scope

2. The scope of the investigation was originally limited to the determination of the effectiveness of one particular impact wrench in transmitting torque to the anchor shells of 6-, 8-, 10-, 12-, 16-, and 24-ft lengths of Williams Hollow Groutable "Rebar" Rock Bolts (U5-8HC-SC5-175) and a 12-ft Williams Solid Bar Rock Bolt (U5-8-SC5-175). During the conduct of the tests, it was decided to also test 2- and 4-ft lengths of the Williams Hollow Rock Bolts.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

PART II: LABORATORY TESTS

Test Equipment

3. The tests were conducted in the laboratory using the following equipment:

   a. Rock bolts as listed in paragraph 2.

   b. Hand torque wrench RDF-1000, manufactured by APCO Mossberg Company of Attleboro, Massachusetts, range 0-1000 ft-lb (Figure 1).

   c. Chicago Pneumatic Impact Wrench, Model CP 982, maximum rated torque 1100 ft-lb (Figure 1).

   d. Load cell, 300-ton maximum load (Figure 1).

   e. Air compressor, Sullair 250-cfm with accompanying hoses (Figure 2).

   f. Anchorage system, simulated drill hole and pipe vise (Figure 3).

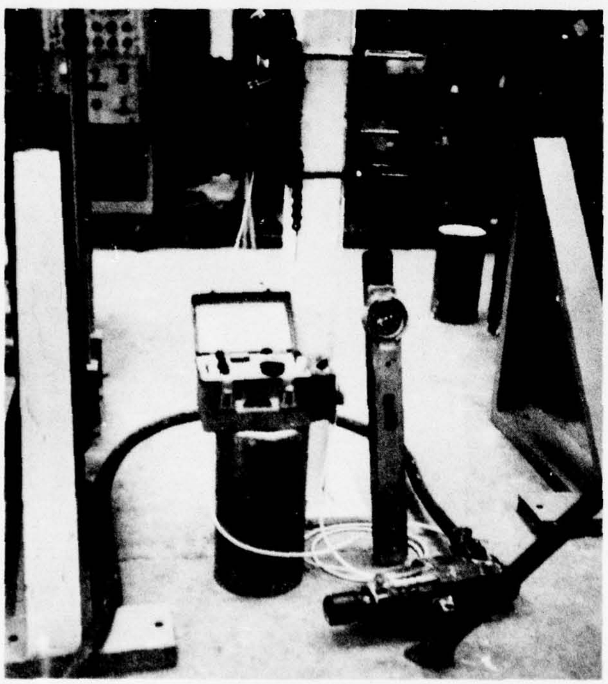

Figure 1. Setup for calibration of impact wrench. (Load cell in pipe vise, impact wrench and torque wrench below)

Figure 2. Sullair 250-cfm air compressor used for tests. Regulator set at 100 psi

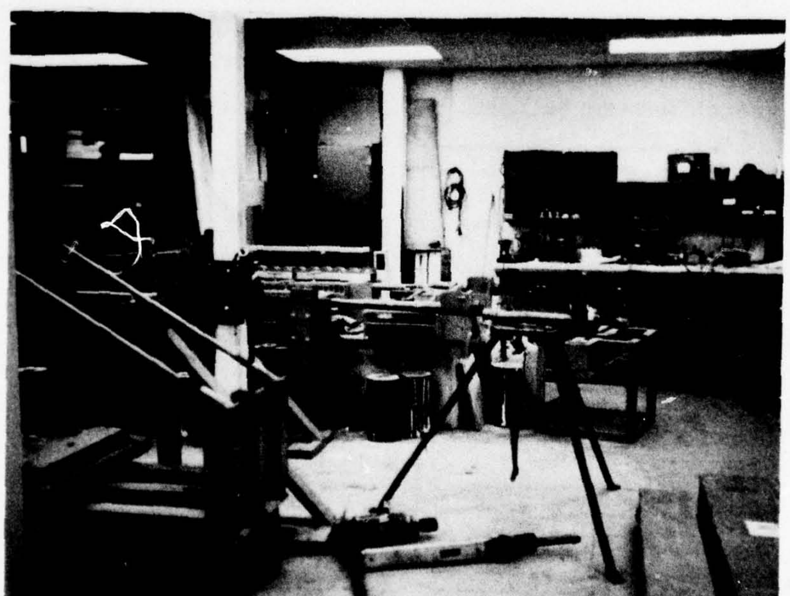

Figure 3. Test setup with 6-ft rock bolt anchored in pipe

Approach

4. The following approach was adopted for the study:

   a. Calibrate hand torque wrench.

   b. Calibrate impact wrench.

   c. Torque rock bolts of different lengths using impact wrench.

   d. Check torque with hand torque wrench and compare transmitted torque measured in tests with theoretical values.

A discussion of the steps involved in this approach is contained in subsequent paragraphs.

Calibration of Hand Torque Wrench

5. The hand torque wrench was calibrated using the procedure illustrated in Figure 4. With the wrench horizontal, the wrench socket was positioned on a rigid bolt head. A weight pan was suspended from the center of the wrench handle (Figure 4) and weights were added. The torque reading and the weight of the pan together with the weights it contained were recorded. The procedure was repeated with increasing weights to obtain torque readings covering the range of torques for which the wrench was to be used. The distance (L) between the center of

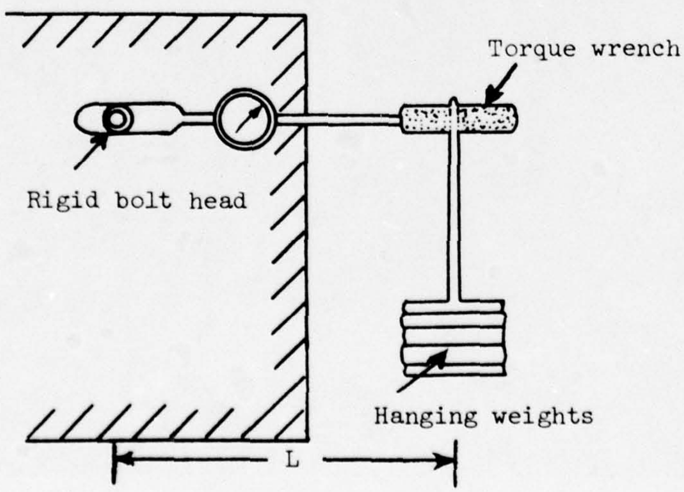

Figure 4. Test setup for calibration of hand torque wrench

the wrench handle and the center of the bolt head was recorded. True torque values were calculated by multiplying the distance (L) by the applied weights. A graph of true torque readings was plotted, and a straight line was fitted to the data points (Figure 5). The slope of

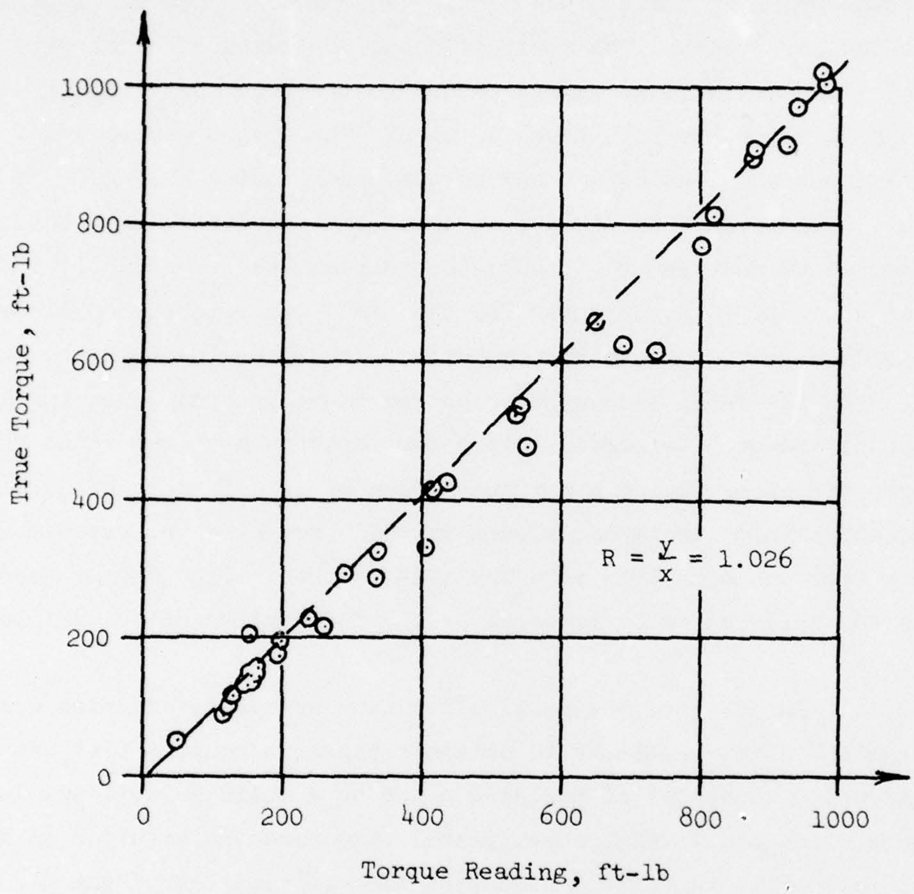

Figure 5. Torque wrench calibration for APCO Mossberg, RDF-1000 wrench

this line was calculated, equal to the ratio (R) of true torque divided by torque reading. As shown, this ratio was found to be 1.026.

Calibration of Impact Wrench

6. Initially, it was believed that an impact wrench could be calibrated by torquing a short bolt for an interval and checking the

torque with a hand torque wrench. Consequently, correlation tests were set up using a drilled core cemented in a steel jacket as a simulated drill hole. The threads on a 1-ft-long, 1-in.-diam solid steel bolt were cleaned and lubricated with graphite. The bolt was equipped with a Williams Type A anchor and was set in the core. Torque was applied with the impact wrench. The applied torque was measured by slowly applying a clockwise (tightening) torque to the bolt and carefully noting the point at which the bolt began to turn. The torque was recorded and the bolt loosened, lubricated, and torqued again using a longer time interval. This procedure did not produce good results in that the maximum measured torque was only about 400 ft-lb and the repeatability of the test was poor (i.e. torquing for the same time interval on different tests produced a wide range of torques). Also, when the bolt was extracted from the core, the anchor cone had to be removed by sawing since the threads had been deformed. Since the impact wrench was rated as being capable of producing a maximum torque of 1100 ft-lb, it was believed that either the impact wrench was not producing the rated torque or the anchor was deforming into the side of the drilled core. Repeatability was believed to be hindered by the deformation of the drilled core.

7. To investigate the possibility that anchor deformation was responsible for the inability to obtain a higher torque, a test was arranged which consisted of torquing a nut on a solid 2-in.-long, 1-in.-diam bolt through a 1/2-in. steel plate. The torquing resulted in a tension failure of the bolt, indicating that the applied torque had produced a tension which exceeded the ultimate strength of the bolt (75,000 lb). For the 1-in. Super-Hi tensile strength bolt used in the test, the torque required to bring the bolt to two thirds of the working load (load at which bolt is stressed to its elastic limit) is 550-ft-lb (Figure 6). Assuming a linear extension of the plot, the torque required to produce a load equal to the elastic limit (60,000 lb) would be 825 ft-lb. The additional torque required to fail the bolt (i.e. a load of 75,000 lb) is not known since the torque-tension graph is probably nonlinear after the elastic limit has been exceeded. Thus, it

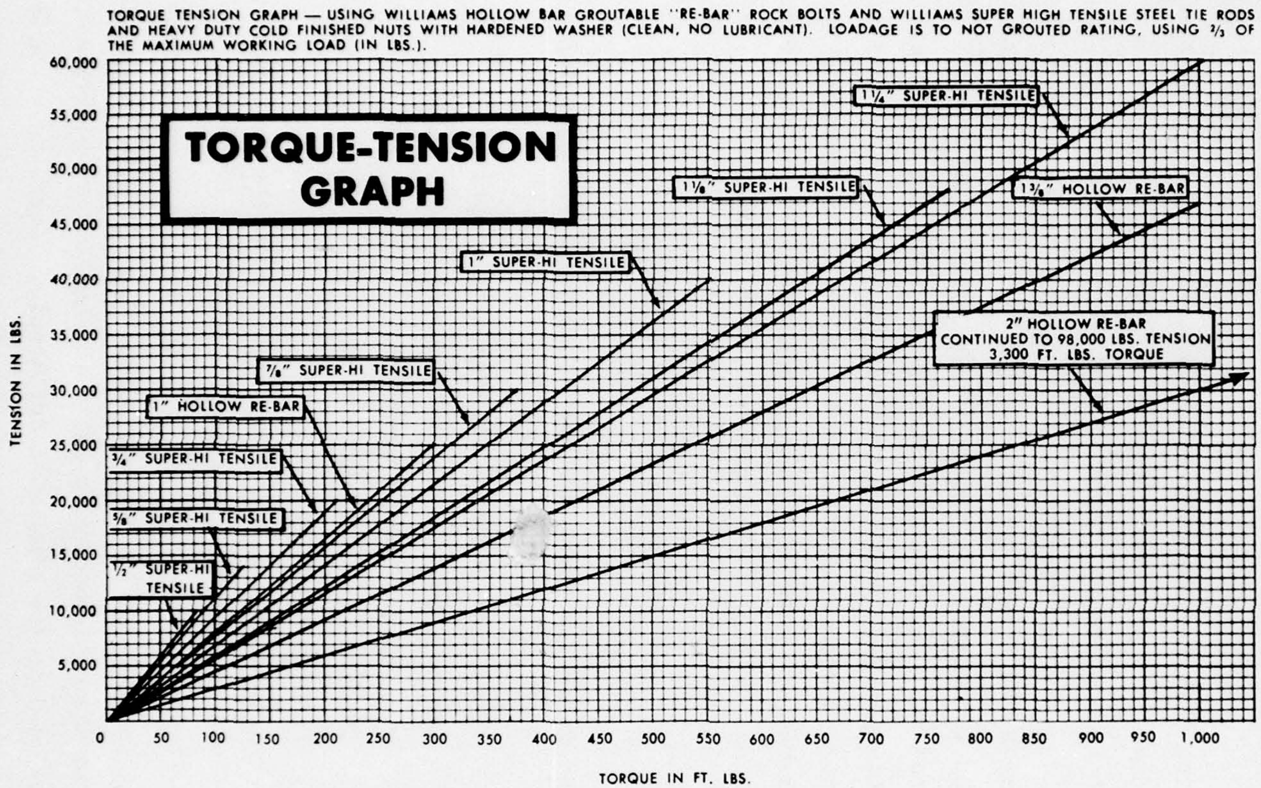

Figure 6. Torque-tension graph

was concluded that the output of the impact wrench exceeded 825 ft-lb and that the failure to obtain repeatable results in calibration was due to deformation of the anchor into the side of the drilled core.

8. Since the short (2-in.) bolt had failed in tension and the core had proved unsuitable for anchoring the bolt, calibration was attempted using 1-ft lengths of 1-in.-diam solid bolts placed through a load cell locked in a pipe vise (Figure 1). The bolt was torqued using a hand wrench to provide an initial load of approximately 1400 lb. This initial loading ensured that there was no "free run time" when the bolt was torqued with the impact wrench. Bolts were then torqued for various time intervals in order to determine if there was a time-torque relationship. The load cell was monitored during the torquing operation to ensure that the yield strength of the bolt was not exceeded during the tests. The time-torque relationship was believed to provide a means of applying different amounts of torque to the rock bolt by regulating the time of torquing. Figure 7 is a plot of the test results.

Torquing of Rock Bolts

9. The following procedure was established for torquing all rock bolts:

- a. Clean and lubricate threads with graphite.
- b. Set rock bolt in simulated borehole.
- c. Torque with impact wrench using 100-psi air pressure.
- d. Check torque with hand wrench.
- e. Record torque.

Subsequent paragraphs describe difficulties encountered and modifications of procedures made during torquing operations.

10. Difficulties were encountered in extracting the rock bolt from the core in the test of the 6-ft bolt; therefore, a thick-walled pipe having an inside diameter of 1-5/8 in. and an outside diameter of 2-3/8 in. was used as the simulated drill hole. Torquing using 2-sec impact periods quickly revealed that the time-torque relationship would not be effective for long bolts. Fifteen 2-sec impact periods were

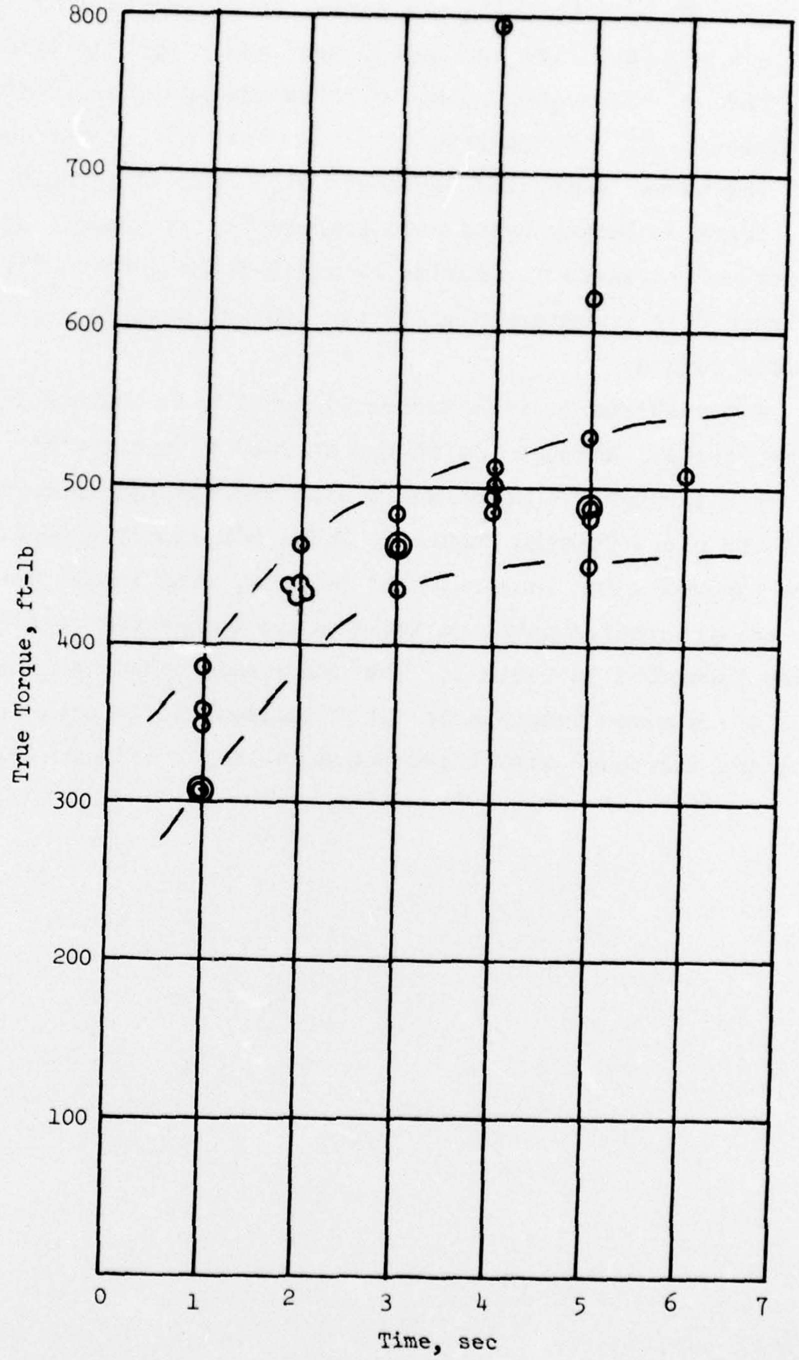

Figure 7. True torque versus time of impacting with Chicago Pneumatic Model 982 impact wrench

needed on the 6-ft bolt to build the torque to its maximum of 205 ft-lb. A 4-sec impact period following these 2-sec impact periods added no additional torque. Subsequent tests were run using longer periods as shown in Table 1. It was apparent from the tests on 6-, 8-, and 10-ft bolts that the torque generally decreased with increasing bolt length. Therefore, tests on longer bolts were temporarily suspended and the 6-ft bolt was cut and threaded to provide 2- and 4-ft-long bolts for further tests. Figure 8 is a summary plot of the test results showing bolt length versus torque.

11. Although the increasing bolt lengths had resulted in decreasing torques (tests 1 through 7), it was decided to run another set of tests (tests 8 through 17) which would also include longer bolts (12, 16, and 24 ft) and a new Chicago Pneumatic Model 982 impact wrench. Again bolts were torqued using longer impact periods, with impact periods generally being repeated until no increase in torque was obtained. Test results are tabulated in Table 1. The new wrench caused an increase in the torque for a given length bolt but indicated, as before, that the maximum torque decreased with increased bolt length (Figure 8).

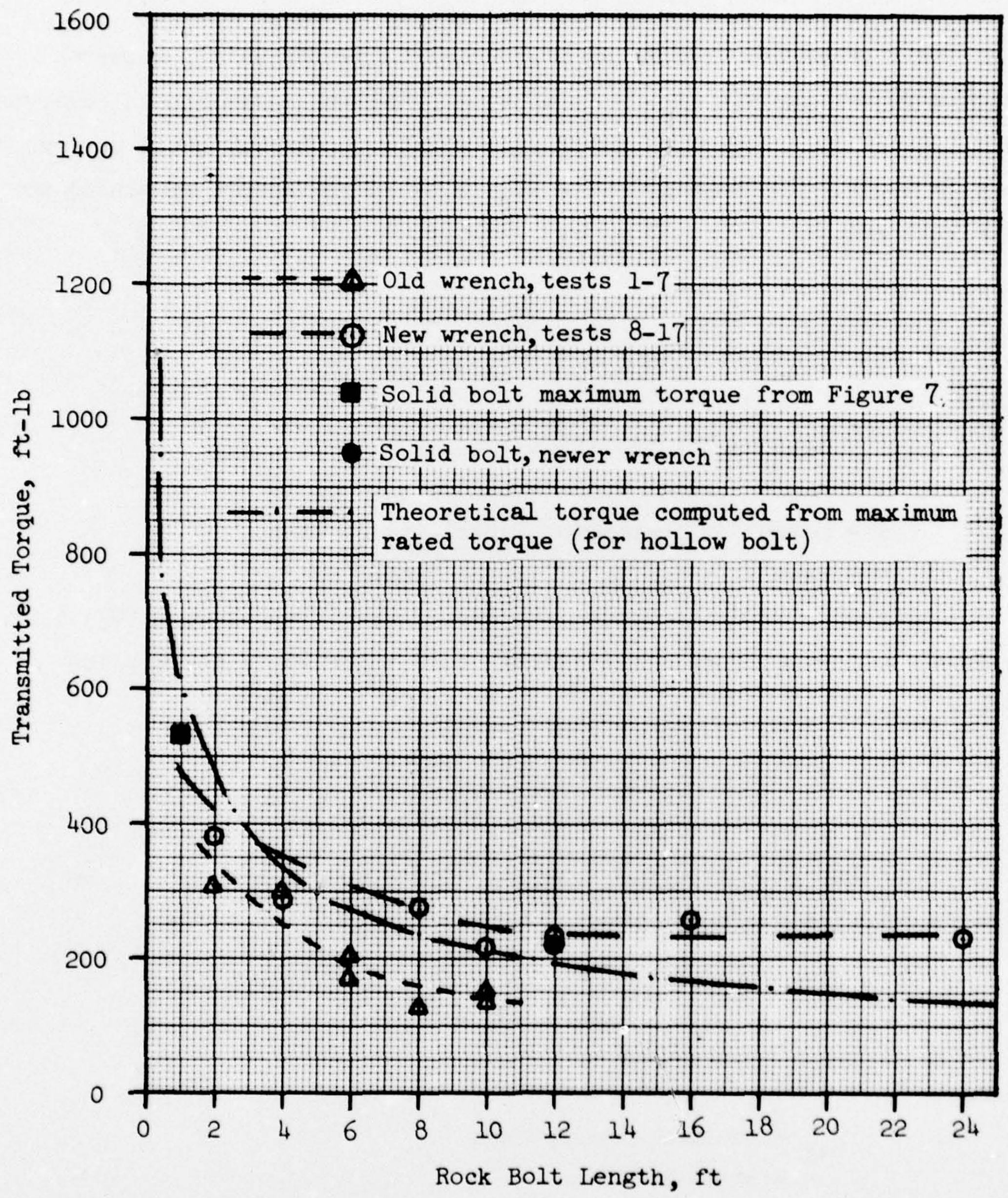

Figure 8. Bolt length versus transmitted torque for Chicago Pneumatic Model 982 impact wrench (1100-ft-lb maximum rated torque)

PART III: COMPARISON OF MEASURED TRANSMITTED TORQUE WITH THEORETICAL TORQUES

12. An impact wrench has a relatively low-torque air motor which imparts rotary inertia to a special type of clutch. The clutch converts this inertia to a series of rotary blows which gradually build up torque in a fastener. The external work (U_e) done by the impact wrench on the rock bolt is:

$$U_e = T\phi \text{ or } I\omega^2 \tag{1}$$

where

T = applied torque, ft-lb

ϕ = angle through which bolt turns, radians

I = moment of inertia of impact wrench hammer

ω = angular velocity of impact wrench hammer

By the principle of conservation of energy, the external work (U_e) must be equal to the internal strain energy (U_i) imparted by the applied force, i.e.,

$$U_e = U_i \tag{2}$$

13. Theoretically, the internal strain energy absorbed by an elastic circular rod subjected to a torque is:

$$U_i = \frac{\tau_{max}^2}{2G}\left(\frac{V}{2}\right) \tag{3}$$

where

τ_{max} = maximum shear stress

G = shear modulus

V = volume of the rod

Thus, for a solid circular rod of radius (r) and length (L), the absorbed internal strain energy is:

$$U_i = \frac{\tau_{max}^2}{2G}\left(\frac{\pi r^2 L}{2}\right) \tag{4}$$

For a hollow rod of length (L), the absorbed internal strain energy is:

$$U_i = \frac{\tau_{max}^2}{2G}\left[\frac{\pi r^2 L}{2}(1 - a^2)\right] \tag{5}$$

where a is the ratio of the inside radius to the outside radius.

14. The maximum shearing stress is related to the applied torque as follows:

$$\tau_{max} = \frac{Tr}{J} \tag{6}$$

where

T = applied torque, ft-lb

r = outside radius, ft

J = polar moment of inertia, ft^4

Substitution of Equation 6 (for τ_{max}) into Equation 5 yields the following equation for internal strain energy:

$$U_i = \left[\frac{\pi r^4(1 - a^2)}{4J^2 G}\right] T^2 L \tag{7}$$

The polar moment of inertia for a hollow bar is given by:

$$J = \frac{\pi r^4(1 - a^4)}{2} \tag{8}$$

Thus, when Equation 8 is substituted into Equation 7 the expression for internal strain energy becomes:

$$U_i = \left[\frac{(1 - a^2)}{(1 - a^4)(1 - a^4)\pi r^4 G}\right] T^2 L \tag{9}$$

For any particular bar, it is evident that the term in brackets is a constant. If a value for the shear modulus (G) of 12×10^6 psi is assumed, the formula for a hollow (1-in. OD and 3/8-in. ID) rock bolt becomes:

$$U_i = 4.92 \times 10^{-4} T^2 L \tag{10}$$

For a solid bar, the value for the internal strain energy is:

$$U_i = 5.50 \times 10^{-4} T^2 L \tag{11}$$

15. If it is assumed that an impact wrench is capable of producing a constant torque (i.e. it has a constant speed and constant moment of inertia), the internal strain energy for a particular type of rod should vary directly with its length. The rated torque of the Chicago Pneumatic Model 982 torque wrenches used in the tests was 1100 ft-lb. This rated torque is based on the torquing of a nut on a solid 1-in.-diam, 4-in.-long bolt in a Skidmore-Wilhelm Bolt Tension Calibrator. Tension is related to torque by calibration with a hand torque wrench. The actual torque varies with each impact tool depending on age and wear; however, if it is assumed that the rated torque is the actual output torque, a value can be calculated for the internal strain energy. The internal strain energy was calculated from Equation 11 using the rated torque (1100 ft-lb) and the length of the calibration bolt (4 in.). The calculated internal strain energy was then used in Equation 10 to compute the maximum torque possible in hollow bolts of varying lengths. These values are shown in Figure 8. The theoretical values of torque for the solid bar can also be computed from Equation 11. However, plotting these values would only clutter Figure 8 and consequently it will suffice to say that the torque for a solid bolt is 94.6 percent of the torque shown for the hollow bolt (compare Equation 10 with Equation 11). A comparison of the theoretical curve for torque versus length with the test results for both the new and the old wrench plotted in Figure 8 indicates that the test results plot in the same general shape as the theoretical curve.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

16. Results of the torque tests on various lengths of rock bolts using a Chicago Pneumatic Model 982 impact wrench rated at a maximum torque of 1100 ft-lb indicate that the transmitted torque generally decreases with increasing bolt length. The decrease is due to the larger amounts of energy required to torque the longer bolts. The transmitted torque (T) was found to decrease with increasing bolt length (L) according to the following equation:

$$T = \sqrt{\frac{c}{L}} \qquad (12)$$

where c is a constant dependent upon bolt size and configuration and upon the type of impact wrench used. Transmitted torque was found to vary with age or condition of the impact wrench as well as with the maximum rated capacity.

17. The difference between the transmitted torques for the 12-ft hollow core bolt and the 12-ft solid bolt was small. Theory predicts that the torque transmitted to the solid bolt should be 5.4 percent lower than that transmitted to the hollow bolt. Table 1 shows that the solid bolt torque was actually 10 ft-lb or 4.7 percent lower than the hollow bolt torque. This difference is considered within the test accuracy.

18. Both wrenches tested produced transmitted torques within the range of torques (50 to 350 ft-lb) recommended by Williams Form Engineering Corporation as necessary to expand the anchor shell in hard or medium rock for the bolts tested. However, it should be noted that the older wrench (tests 1-7) had reached a lower torque value for the 10-ft bolt and may not have produced the torque necessary to expand the anchor shell for longer bolts. Furthermore, it should be noted that all tests were performed under laboratory conditions with special precautions to ensure lubrication of all threads; with a constant air pressure; and

with an ideal drill hole free from water, loose rock, and other hindrances. Thus, these results may not be reproducible under field conditions.

Recommendations

19. It is recommended that impact wrenches to be used for torquing rock bolts be proof tested on a device such as the Skidmore-Wilhelm Bolt Tension Calibrator before acceptance. Since theory and laboratory testing have indicated a decreasing torque with increasing bolt length and a decrease in transmitted torque with increased wrench wear, it is further recommended that field tests with various bolt lengths be performed under conditions similar to those under which the impact wrench is to be used. In further testing, it is recommended that laboratory testing be closely coordinated with field testing. It is also recommended that the effect of exceeding the maximum allowable shearing stress in torquing be investigated.

Table 1

Results of Rock Bolt Torquing Tests

Test No.	Bolt Length ft	Time of Torquing sec	Cumulative Time sec	Measured Torque ft-lb	True Torque ft-lb	Remarks
1	6	2	2	25	26	Fifteen 2-sec intervals. Test set up in rock. Difficulty encountered removing bolt from core
		2	4	75	77	
		2	6	125	128	
		2	8	125	128	
		2	10	125	128	
		2	12	125	128	
		2	14	135	138	
		2	16	150	154	
		2	18	150	154	
		2	20	175	180	
		2	22	200	205	
		2	24	170	174	
		2	26	150	154	
		2	28	175	180	
		2	30	200	205	
		4	34	200	205	
2	10	60	60	135	138	Test conducted in thin-walled pipe. Pipe deformed by expansion of shell
3	10	60	60	100	103	Repeat of test using thick-walled pipe
		60	120	125	128	
		30	150	125	128	
		60	210	150	154	
4	8	4	4	50	51	Thick-walled pipe used
		5	9	50	51	
		30	39	75	77	
		60	99	115	118	
		65	164	115	118	
		60	224	125	128	
5	6	30	30	165	169	Retest of test 1 using thick-walled pipe
		15	45	165	169	
6	4	30	30	190	195	6-ft bolt cut and threaded to form 2- and 4-ft bolts
		30	60	270	277	
		30	90	290	298	
7	2	7	7	200	205	6-ft bolt cut and threaded to form 2- and 4-ft bolts
		15	22	250	257	
		30	52	300	308	
		30	82	280	287	
		60	142	300	308	
8	2	20	20	290	298	Begin using new model 982 impact wrench
		30	50	310	318	
		30	80	320	328	
		30	110	350	359	
		30	140	370	380	Maximum
		30	170	370	380	
9	4	30	30	230	236	
		30	60	250	257	
		30	90	280	287	
		30	120	280	287	
10	24	30	30	200	205	
		30	60	225	231	
11	24	60	60	225	231	
12	24	60	60	225	231	Coupling used at anchor end
13	16	60	60	215	221	
		60	120	250	256	
14	12	60	60	210	215	
		60	120	225	231	
15	12	30	30	175	180	Solid bolt
		60	90	215	221	Maximum
		30	120	190	195	
16	10	30	30	175	180	
		60	90	210	215	Maximum
		30	120	200	205	
17	8	30	30	250	257	
		30	60	265	272	
		30	90	265	272	

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